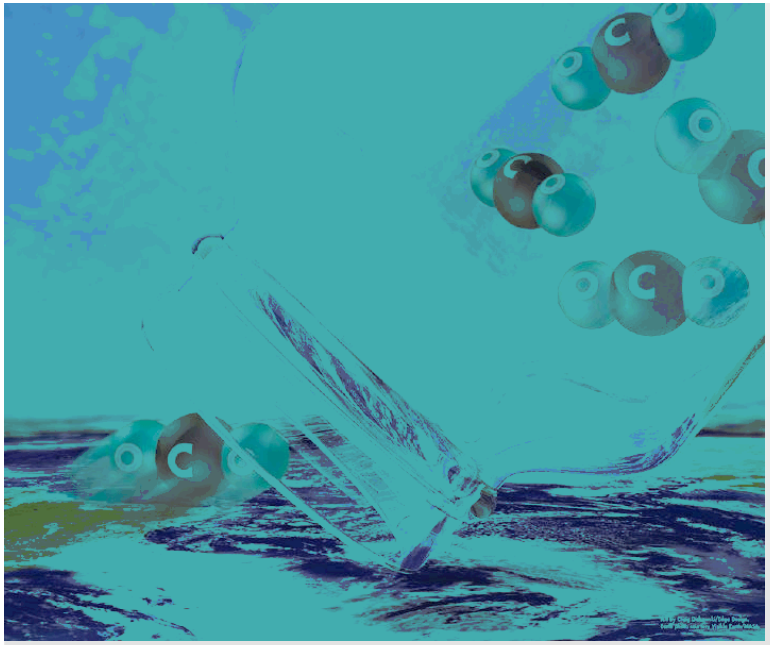

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CO2 Capture and Storage

California Energy Commission 2007 Integrated Energy Policy Report Committee Workshop

May 29, 2007

Sacramento, CA

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Director, Generation

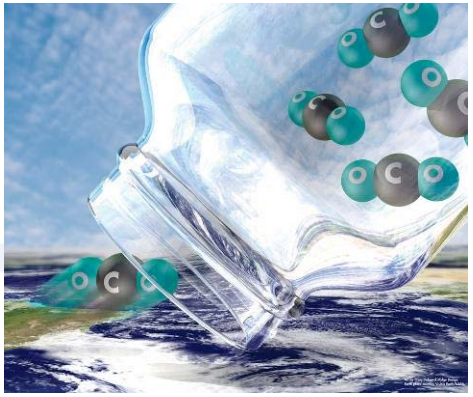
Outline of Presentation

- Capture of CO_2
- International perspective on clean coal
- Discussion

Key Messages
CO_2 Capture and Storage (CCS)

- CCS for coal is an important contribution in almost all projections, and very important in EPRI's
- No coal technology with CCS is preferred for all coals, elevations, site conditions
- RD&D is needed, especially >1 MTY storage demonstrations, advanced materials for efficiency improvements and advanced gas turbines capable of using hydrogen to meet cost and efficiency goals
- It will take high CO_2 costs, incentives or stringent control requirements to make CCS competitive

Preparing for Carbon Constraints



Variation of Plants
Variation Geology

CO_2 Capture

- Plant Efficiency
- Capture Technology
- Capture Pilots
- Capture Demonstrations

Confirmed Long Term Sequestration

- Test Multiple Geologies
- Well Integrity
- Monitoring

Address Societal Concerns

- Liability
- Health
- Public Acceptance

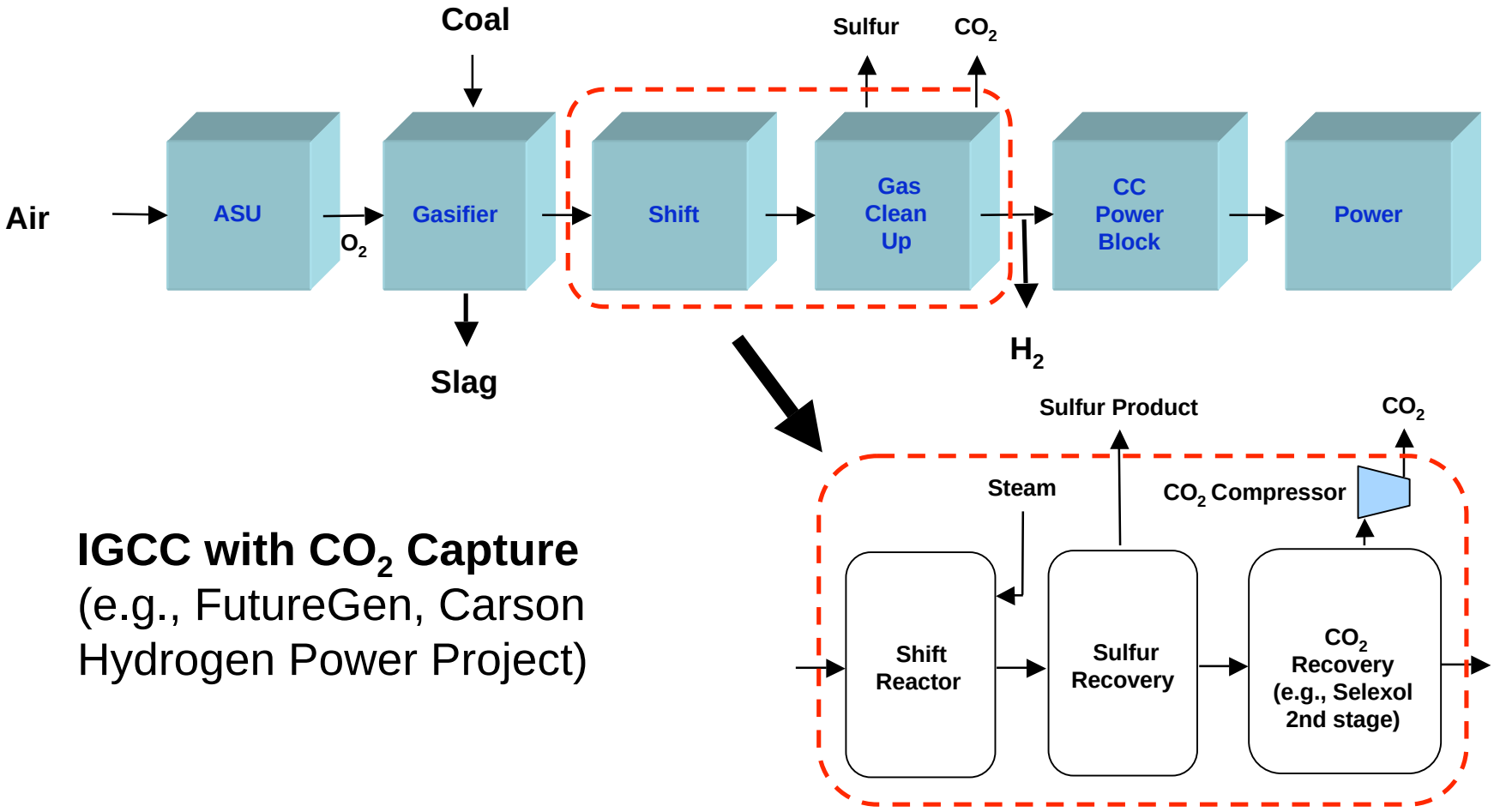
Multiple Challenges Requiring Concurrent Resolution.

Options for Reducing CO_2 from Coal Plants

Generating Technology	CO_2 Approach	Challenges
IGCC	**Improve Efficiency** **Capture CO_2**	**Cost & Integration of IGCC** **Storage**
Pulverized Coal	**Improve Efficiency** **Capture CO_2**	**Integration of CO_2 Capture** **Penalty of Capture CO_2** **Storage**
Oxy Firing	**Improve Efficiency** **Production of CO_2**	**Technology (O_2)** **Storage**

CO_2 Storage Policy a Challenge for All Technologies.

Integrated Gasification Combined Cycle (IGCC) With CO_2 Removal



IGCC with CO_2 Capture
(e.g., FutureGen, Carson Hydrogen Power Project)

Needs Space, Energy and Integration.

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Coal Gasification Plants w/CO_2 Capture (Today)

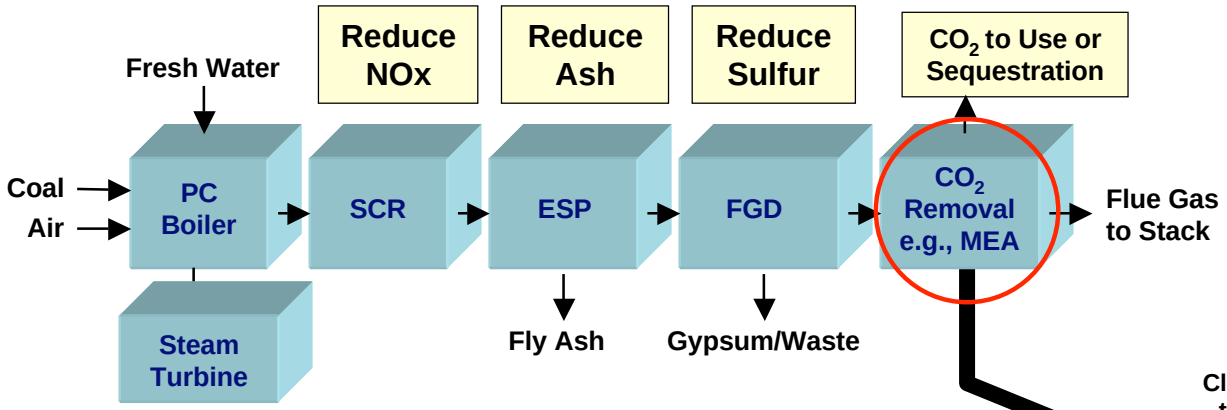
- IGCC and CO_2 removal offered commercially:
  - Have not operated in an integrated manner
- Three U.S. non-power facilities and many plants in China recover CO_2
  - Coffeyville
  - Eastman
  - Great Plains
- Great Plains recovered CO_2 used for EOR:
  - 2.7 million tons CO_2 per year
  - ~340 MWe if it were an IGCC

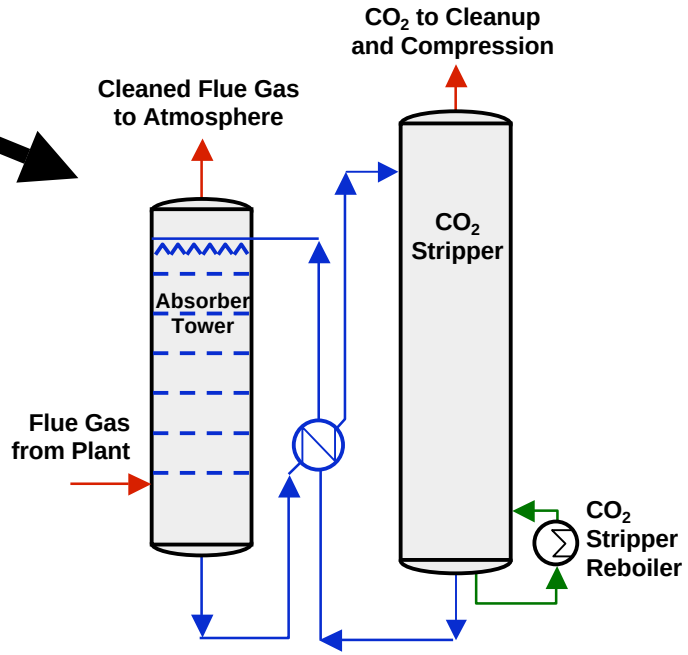
The Great Plains Synfuels Plant
http://www.dakotagas.com/Companyinfo/index.html

Weyburn Pipeline
http://www.ptrc.ca/access/DesktopDefault.aspx

No Coal IGCC Currently Recovers CO_2

Pulverized Coal With CO_2 Capture "Today"





- Pre-condition Flue Gas (Clean)
- Absorb CO_2
- Strip CO_2
- Requires significant energy

Needs Space, Integration and Energy.

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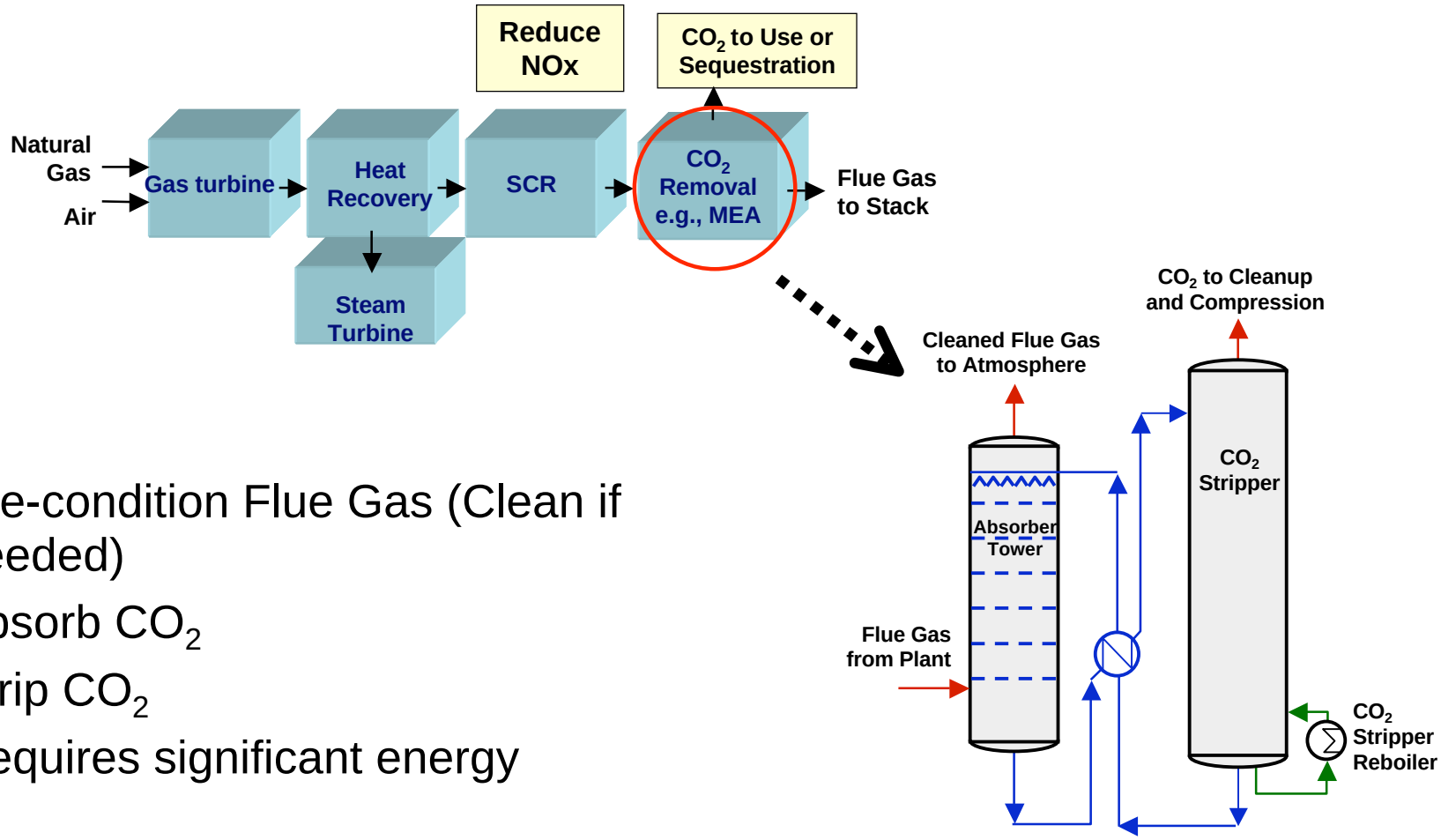
Natural Gas With CO_2 Capture



- Pre-condition Flue Gas (Clean if needed)
- Absorb CO_2
- Strip CO_2
- Requires significant energy

Needs Space, Integration and Energy.

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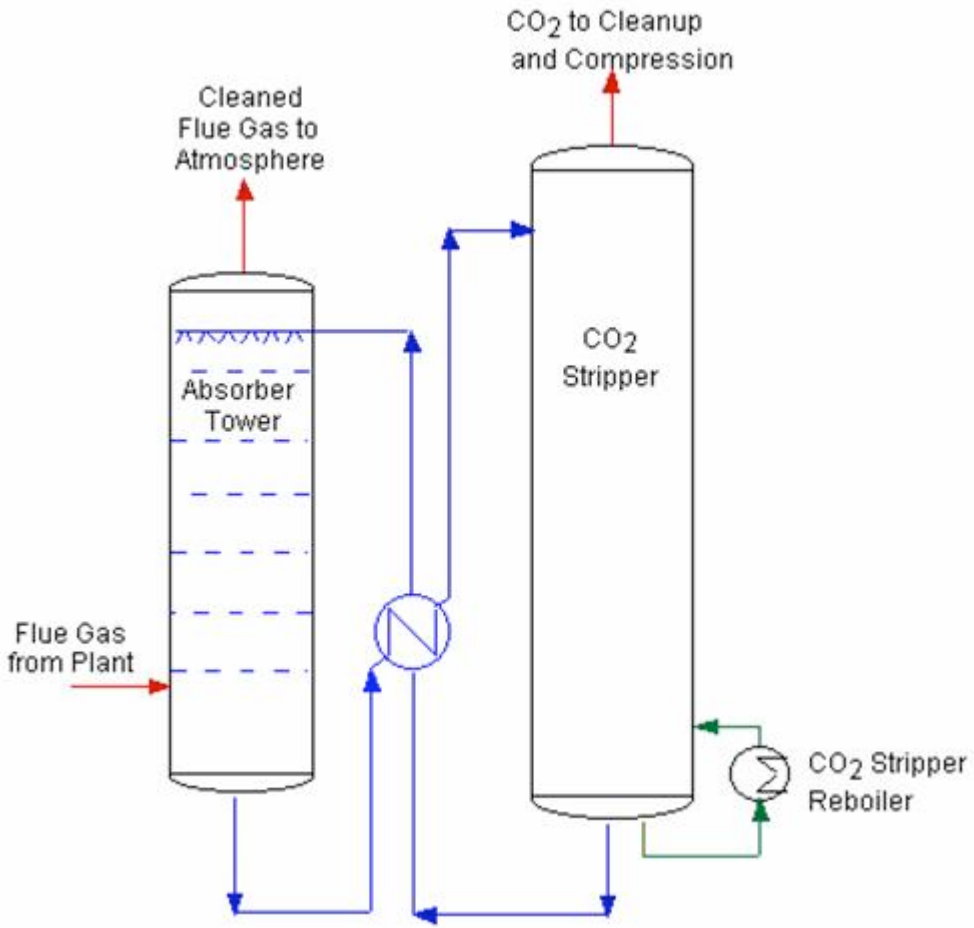
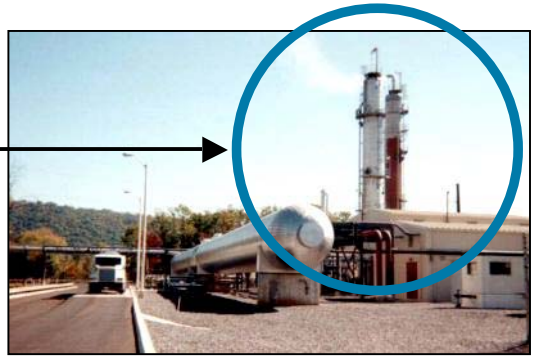
CO_2 Capture by Chemical Absorption
(anything that likes to capture CO_2 does not like to let it go)



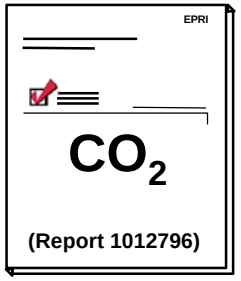
- Amine type processes are commercially available -Fluor, Kerr McGee, MHI and have been built at 300 mt/day CO_2 (500 MW PC produces ~10,000 mt/day CO_2)
- Requires extensive flue gas pretreatment
  - » Essentially no NO_x or SO_2
- Large reboiler steam requirement
  - » Large net output reduction
  - » Make-up power source for Retrofit of existing plant?
- Looking at options for reduced steam consumption (e.g., chilled ammonia)

PC Operating Units w/ CO_2 Capture (Today)

- Three U.S. small plants in operation today:
  - Monoethanolamine (MEA) based
- CO_2 sold as a product or used:
  - Freezing chickens
  - Soda pop, baking soda
  - ~140 $/ton CO_2
- 300 metric tons recovered per day:
  - ~15 MWe power plant equivalent
- Many pilots planned and in development:
  - 5 MW Chilled Ammonia Pilot
  - Many other processes under development



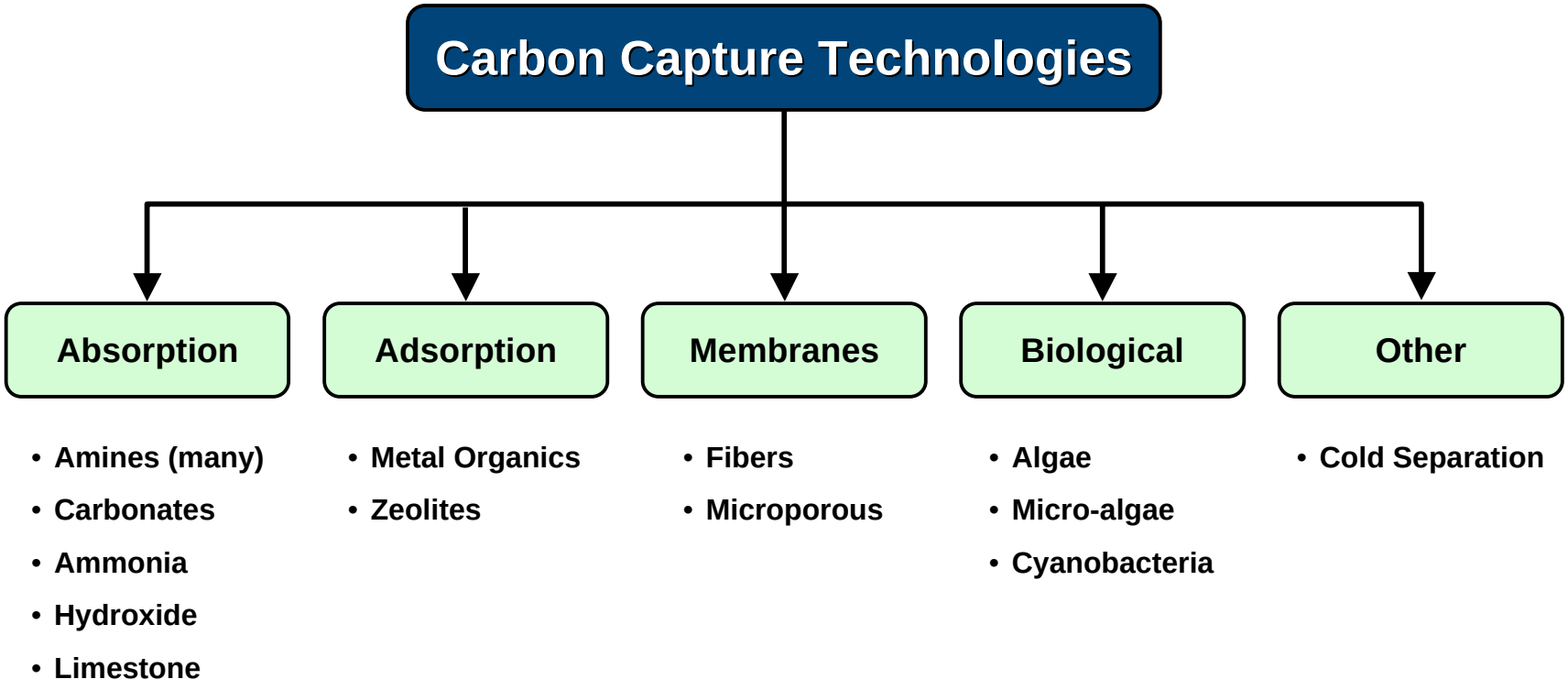
AES Cumberland ~ 10 MW



Assessment of Post-Combustion Carbon Capture Technology

Only Demonstrated on a Small Scale to Date.

Many Post Combustion CO_2 Capture Technologies Under Development



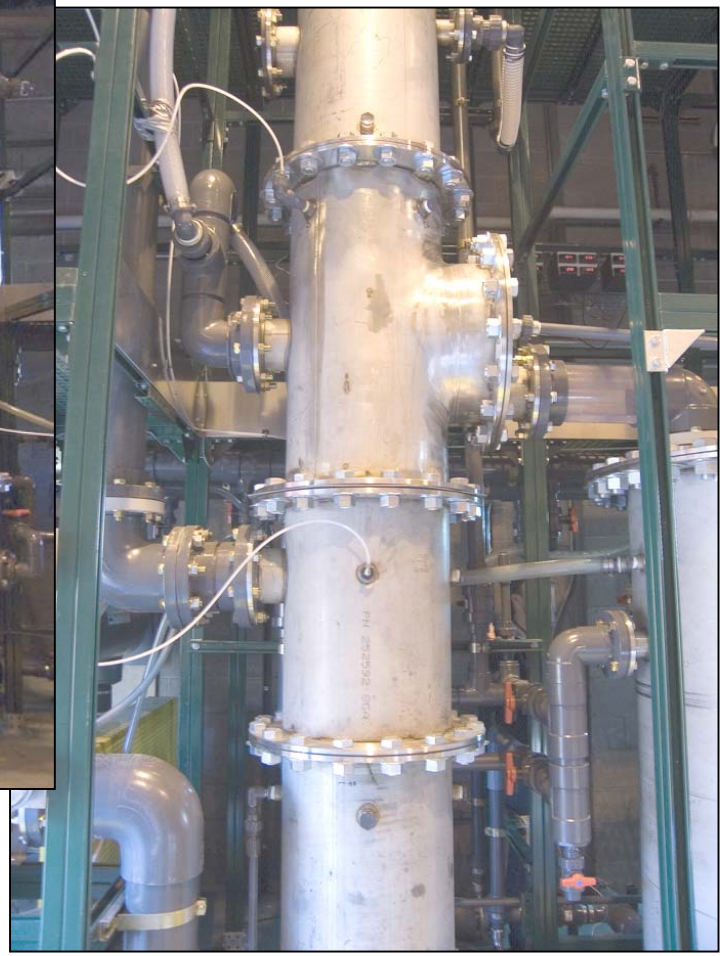
Which might meet DOE goals of ≤ 10% energy penalty, ≤ 20% COE increase?
- **1-5 MW demo in 5 yr meeting/approaching one goal**
- **1-5 MW demo in 10 yr at/better than both goals**

0.25 MW Menlo Park SRI Lab Pilot Used to Confirm Thermal Balance, Provide Design Guidance for Pilots

Larger Pilots planned in Wisconsin, West Virginia, Demo in Oklahoma

Absorber towers, water wash and hold tanks

First absorber details



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IGCC Units Designed for CO_2 Capture at Commissioning

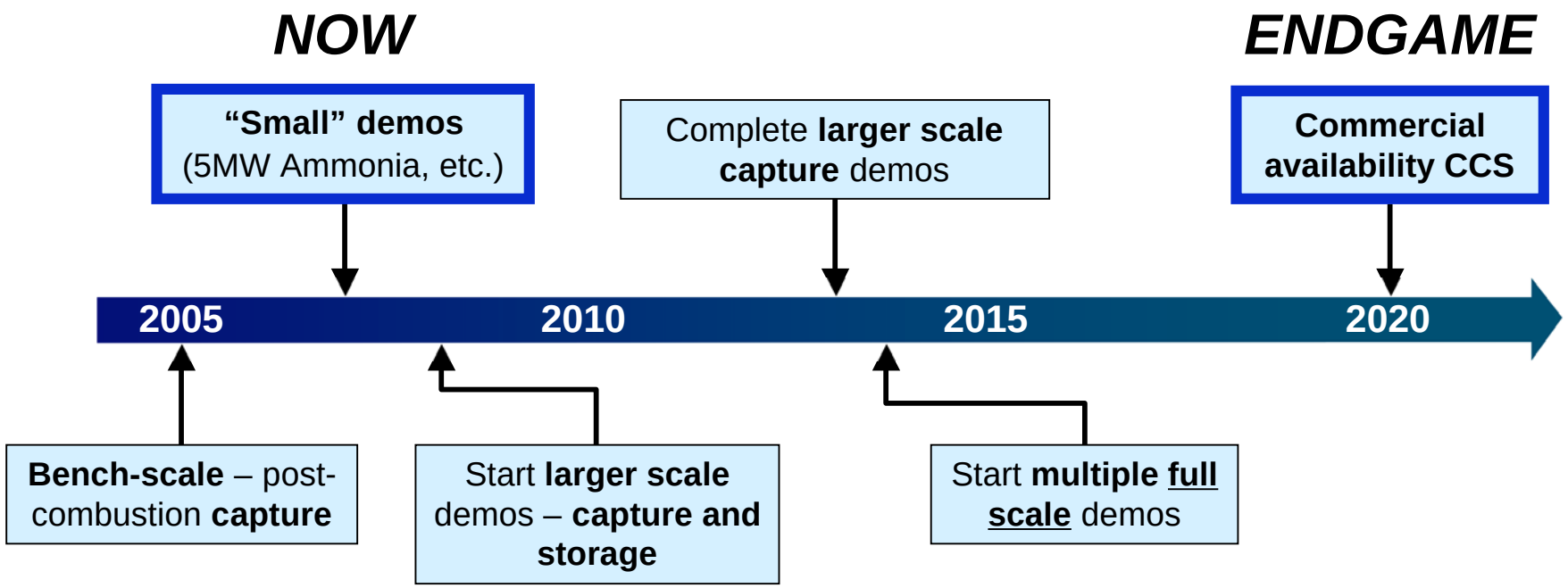
- Current EPRI CoalFleet for Tomorrow® IGCC Knowledge Base of Gasification Projects
  - **66 North America projects**
  - **38 International projects**

15 Gasification Projects Aimed at C&S from Day 1	
• Carson Hydrogen Power Proj.	• RWE
• Xcel IGCC high altitude	• Shell Australia
• FutureGen Demo	• Stanwell ZeroGen Demo
• USA – Undisclosed	• Centrica / Progressive Energy
• Hunton 10–15%	• E.ON UK
• Indiana Gasification	• Hatfield UK
• North America – Undisclosed	• GreenGen Demo China
	• BP Peterhead UK (cancelled)

Potential Timeline for Full Scale CO_2 capture and Storage

- Operate and learn by doing a full scale capture, transport and storage system
  - test the operability, integration and performance and economics
- Time to permit, design and build a full scale capture facility as a new unit – at least 5 years
- Testing of CO_2 storage may take 3-4 years
- Verification of the site once injection is complete should be monitored for several years (3-4 likely minimum)
- BY 2020
  - Large scale demonstrations and a few pioneering installations like FutureGen, BP Carson
  - Pioneering post combustion capture like AEP Northeastern plant with chilled ammonia

A Roadmap for CO_2 Storage and Post-Combustion Capture



Needs: Multiple large-scale CAPTURE and STORAGE demos

Timing: 2020 endgame ➔ start today, parallel paths

Realistic? A challenge – technical, policy, funding

Source: DOE-NETL Carbon Sequestration R&D Roadmap
Modified to add Chilled Ammonia example

What's Next – What's Needed for CCS

- Acceleration of the Industry efforts worldwide in addition to governmental efforts – new pilots, demonstrations, initiatives
- Cost reductions and efficiency improvements for capture "systems"
- Large scale testing of storage of CO_2 in deep saline reservoirs:
  - Permitting w/ acceptable risks
  - EPRI invites organizations to contact us if interested in support for accelerated large scale CO_2 capture and storage demonstrations and other work related to CO_2.

Questions?

- More information on CO_2 capture and storage is available in the current EPRI journal available free at www.epri.com

Backup Slides

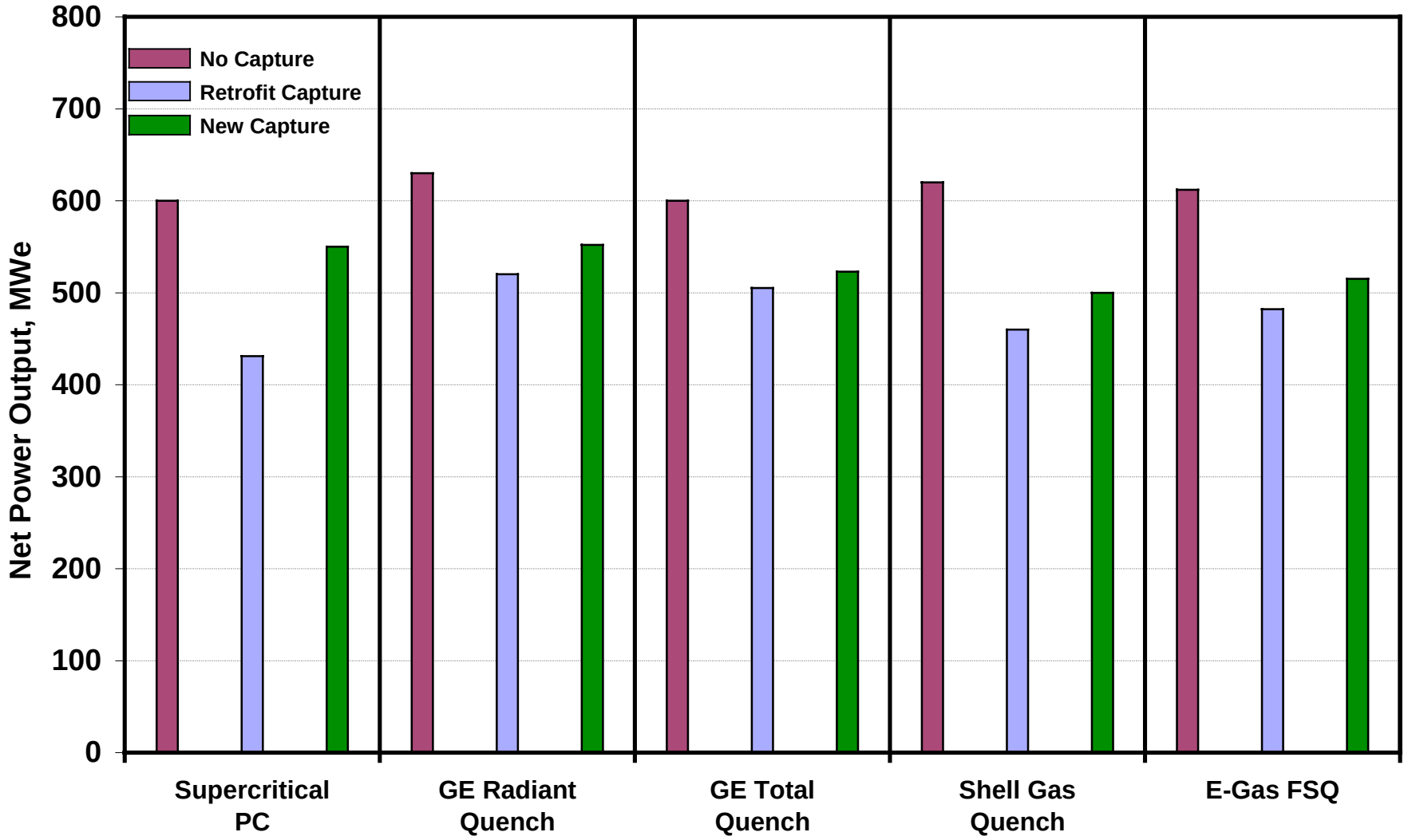
GHG CO_2 Performance Standard (1100#/MWh)

- 1100 lb/MWh target (typical modern plant with no CCS on western coal ~ 38% efficiency ~ 1950 #/MWh)

Discussion:

- Necessitates >**45%** reduction from an IGCC or PC plant with 37–39% efficiency
- In short term, partial CO_2 capture may become an option
  - For IGCC this could mean treatment of one "train" or a single "shift" reactor and partial treatment
  - For PC this will mean a big scale up of technology and large steam use but likely ½ the gas treated @ 90%
  - Possible off peak steam use or solar assist in regeneration might be plausible (Imperial College in UK studying)

EPRI PC and IGCC Net Power Output With and Without CO_2 Capture (Illinois #6 Coal)



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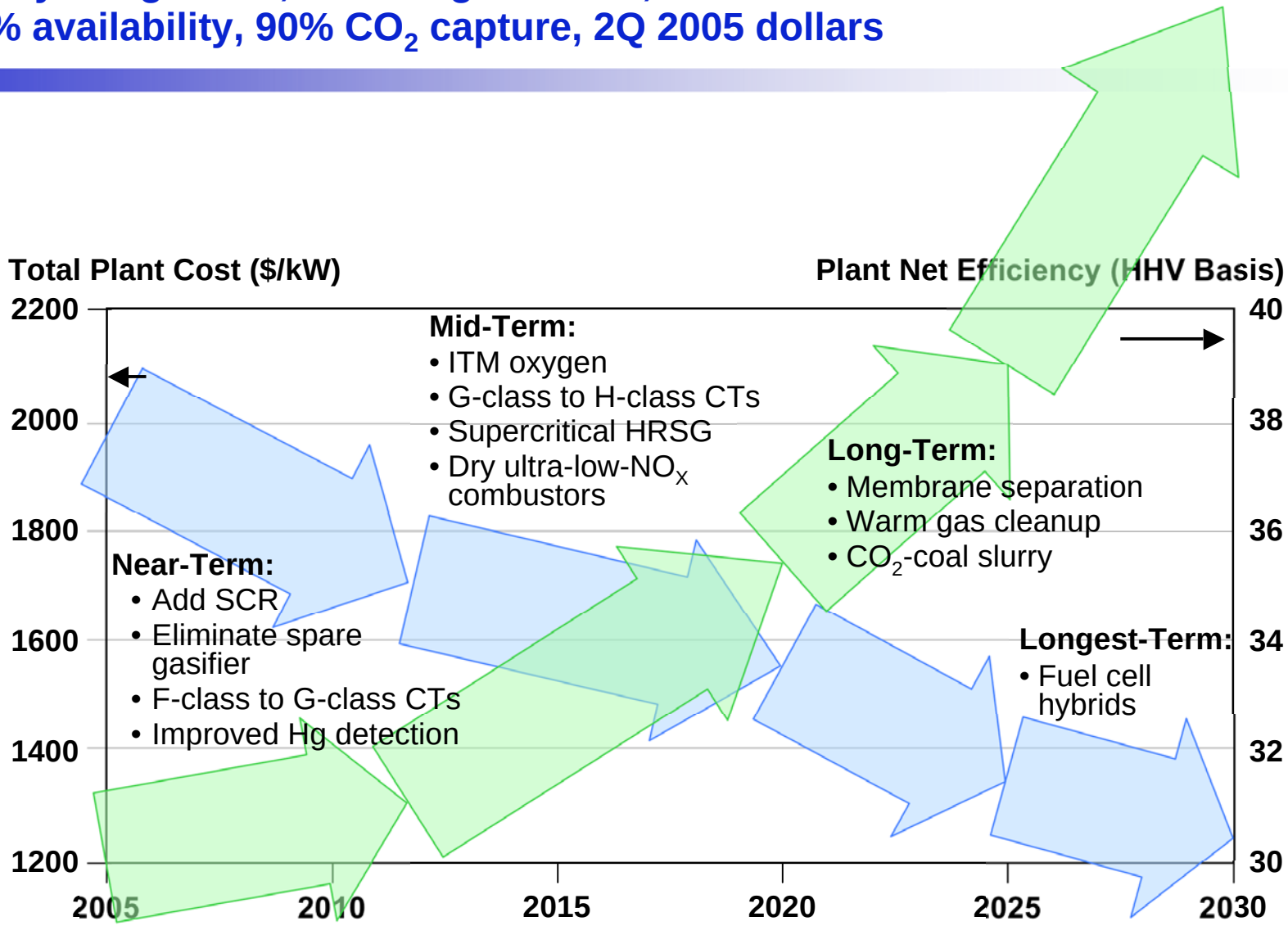
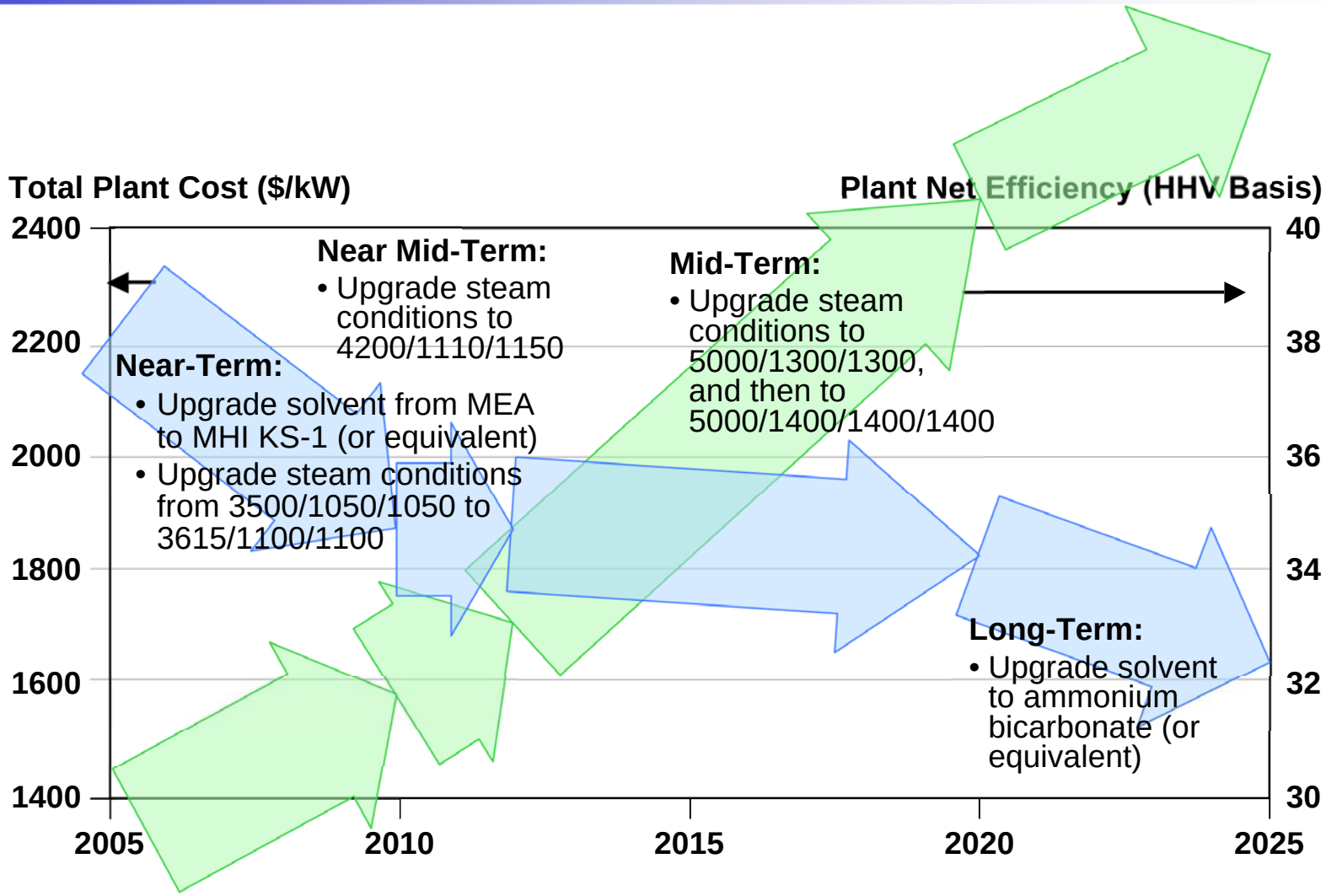
IGCC RD&D Augmentation Plan—Expected Benefits Case:
Slurry-fed gasifier, Pittsburgh #8 coal, 90% availability, 90% CO_2 capture, 2Q 2005 dollars



USC PC RD&D Augmentation Plan—Expected Benefits Case:
Pittsburgh #8 coal, 90% availability, 90% CO_2 capture, as reported data from various studies (not standardized)



E.ON UK comments on projects in Europe

Project	Location	Scale, MW	Timing	Comments
BP/SSE	UK, Peterhead/Miller	350	2014	NGCC + CCS, EOR
Vattenfall	Germany, Pilot Germany, Commercial	30 ???	2008 2020	Oxyfuel, no CCS Lignite
Shell/Statoil	Norway	850	2011	NGCC + CCS, EOR
RWE Power	Germany	450	2014	IGCC + CCS
Progressive Energy	UK, Teeside	800	2011	IGCC + CCS, EOR Coal, petcoke
PowerFuels	UK, Hatfield	900	Post 2012	IGCC + CCS
E.ON UK	UK, Killingholme	450	2012	IGCC + CCS
RWE nPower	UK, Tilbury	1000	2016	S/C with CCS
SSE	UK, Ferrybridge	500	?	S/C Retrofit

Now deferred

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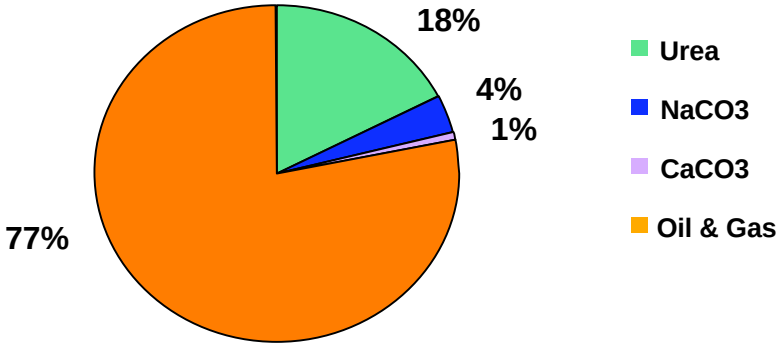
US Experience with CO_2 Pipelines for EOR

Source: R Williams presentation to NREL

Current US Annual CO_2 Utilization

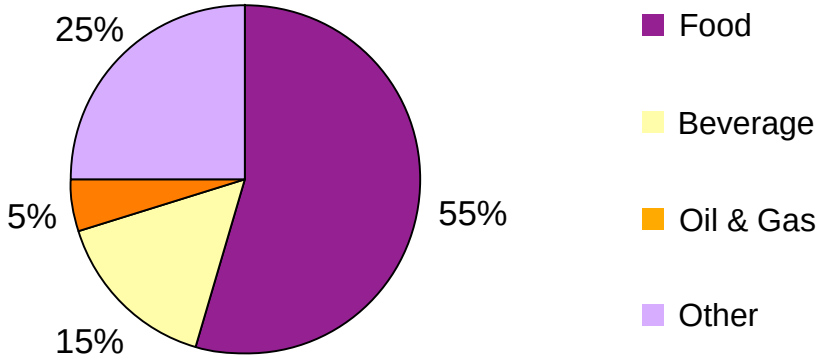
Mainly Enhanced Oil Recovery

Gaseous Consumption = 30.9 million metric tons



Liquid/Solid Consumption = 7.1 million metric tons

Mainly Food

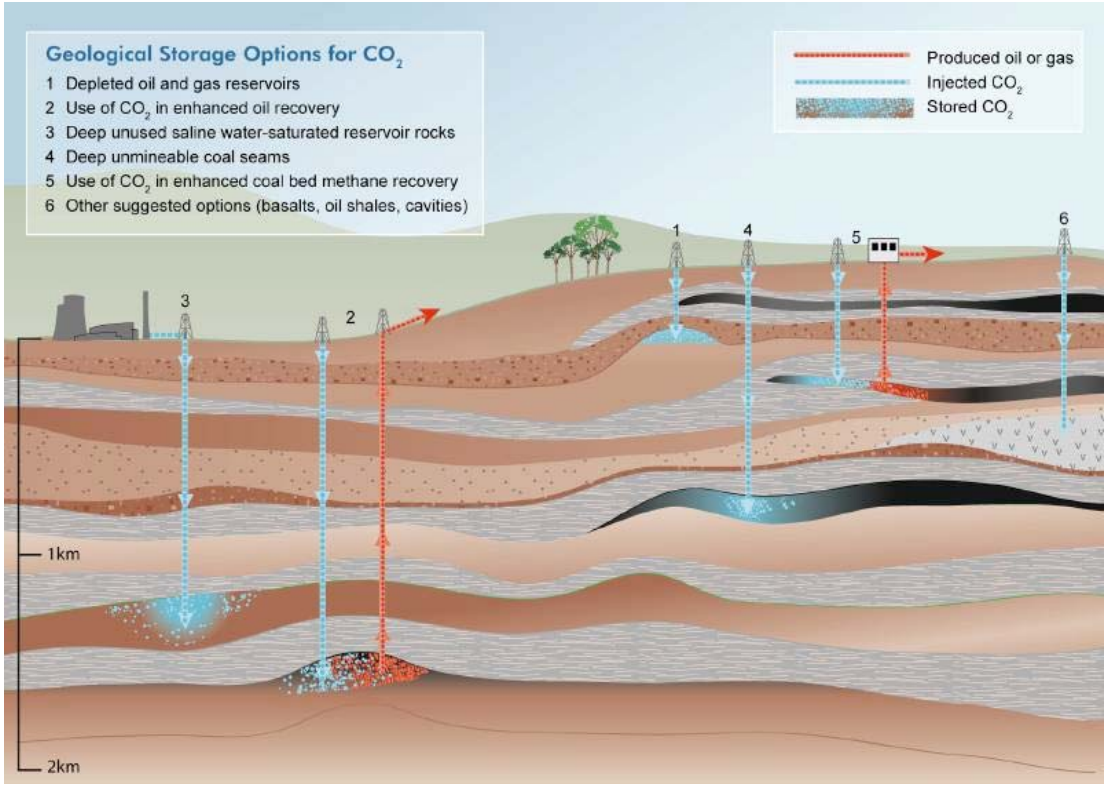


~40M Tons of Use vs. 6B Tons Currently Emitted

Source: Howard Herzog / MIT Laboratory for Energy and the Environment

CO_2 Sequestration/Storage – Main Focus of Injection Into Geological Formations

- **Saline reservoirs**
  - **100's yrs capacity**
  - **Little experience**
- **Economical, but lesser capacity options**
  - **Depleted oil & gas reservoirs/enhanced oil recovery**
  - **Unmineable coal beds/enhanced coal-bed methane recovery**
- **Deep ocean injection not acceptable today**



Courtesy of Peter Cook, CO2CRC

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How Does Saline Reservoir Sequestration Work?

- Inject into deep, high salinity reservoirs
  - No impact on drinking water
- Limited data
  - Few wells penetrate reservoirs
- Large volume potential for storage
  - Order of magnitude larger than oil
- Reasonably well distributed across country

CO_2 Capacity Estimates by Partnership
Saline Formations

	Low		High	
	(Billion Metric Tons of CO_2)	(Billion Tons of CO_2)	(Billion Metric Tons of CO_2)	(Billion Tons of CO_2)
BIG SKY	271	299	1,085	1196
MGSC	29	32	115	127
MRCSP	47	52	189	208
PCOR	97	107	97	107
SECARB	360	397	1,440	1587
SOUTHWEST	18	20	64	71
WESTCARB	97	107	388	428
Total	**919**	**1,014**	**3,378**	**3,724**

This map displays saline formation data which were obtained from the RCSPs and other external sources and compiled by NATCARB.